ORIGINAL ARTICLE

DELTOID ANTERIOR CONTRACTION IN MANEUVERING THE STEERING WHEEL

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ABSTRACT

While driving, a driver is required to control the steering wheel to change direction. The driver's muscles of the upper limbs and shoulders are involved in such a task. Therefore, an assessment of the driver's physiology according to certain condition is necessary to improve driving comfort and safety. This study aims to investigate the driver's Deltoid Anterior (DA) muscle activity while operating the steering wheel. Eleven test subjects were recruited for an experiment using a car simulator. They were required to remain in the car seat and perform the task of steering the wheel. Surface electromyography (SEMG) was used to record each subject's muscle contraction while turning the steering wheel to the right and left by several degrees. According to the findings, 45 degrees turning recorded the highest Root mean Square (RMS) value for DA. In addition, DA muscle activation increased with more degrees turning.

***Keywords**: Deltoid anterior, steering wheel, SEMG, driver, discomfort, distant seated posture*

INTRODUCTION

Driving physically demands a driver to maintain his/her posture in a constrained space[1-3]. Throughout the task of driving, a driver remains in direct physical contact with the car seat, steering wheel, gear knob and pedals[4]. Such a constrained space may hinder the driver from adopting his preferred driving posture[5]. While driving, it is essential for the driver to be able to easily reach all necessary items such as the steering wheel, gear shift and pedals. In addition, the driver is required to pay extra attention to the road to ensure a safe ride. Each driver has his or her own specific style with respect to driving condition. However, proper seat adjustment, in addition to the position of steering wheel, gear or lever shifting and pedals can ensure comfortable driving[6].

The steering wheel is the main controller of a car as it functions to manoeuvre the direction of a moving vehicle. As stated by Liu et al.[7], vehicles are generally operated in a closed loop with the driver. Thus, the dynamic characteristics of the driver's steering are needed in order to optimize the vehicle's dynamic behaviour. There are many hand grip styles when driving, depending on a driver's preference. Most drivers tend to put their hands at 9:15 and 10:10 positions[8-11]. Additionally, driving normally requires the driver to be in a semi static position in order to perform rotation activity, which involves repetitive movements of the upper limbs[12]. According to related literature, more than fifty muscles of the upper limbs and shoulders are involved in controlling the steering wheel[3, 13-14]. In this study, only one significant muscle was observed based on previous research. Pandis et al.[15] found that the deltoid showed two times higher activation compared to other muscles of the upper limb. Repeated high muscle activation could result in muscle fatigue particularly to the deltoid. Hence, this study will examine drivers' Deltoid Anterior (DA) muscle activity while driving.

To do this, the study will investigate the DA muscle contraction while engaging in the task to control the wheel. Surface electromyography (SEMG) technique was used to record muscle activity. Based on the assessment, the relationship between the degree of steering wheel turning and muscle contraction in certain posture can be determined.

METHODS

Subject

Eleven healthy subjects with no previous record of health problems participated in the study (mean age of 28 years, mean height = 161 cm, mean weight = 56 kg). Informed consent was obtained from each subject, and ethical approval was granted by Universiti Kebangsaan Malaysia. Each subject was required to attend one session, either in the morning (from 9 am to 12 pm) or in the afternoon (from 2 pm to 5 pm). As a prerequisite, all respondents must have a full Malaysia driving license, with at least three years of driving experience and aged between 22 to 35 years old. The age limit was proposed to reduce variations in the results. This is because people of different age groups have slight perceptive variations towards driving[16].

Apparatus

A driving simulator as shown in Figure 1 was used in the study. Its design is quite similar to that of a Malaysian made compact car. The simulator comprises an adjustable driver's seat (inclination of the backrest, lower or elevate head rest, forward or backward seat), steering wheel, clutch, accelerator and brake pedals, handbrake, and manual gear shift. A screen is located in front of the driver and the simulator comes with a virtual dashboard. In this study, test subjects were required to grip the steering wheel of the simulator and respond according to instructions given by the researcher.

Figure 1- Simulator design

Experiment protocol

All the subjects were given some time to familiarise themselves with the car simulator setup and car seat adjustment prior to the experiment. This was to allow them to adapt to the seating environment and fabrics. Figure 2 demonstrates the process flow for the subject.

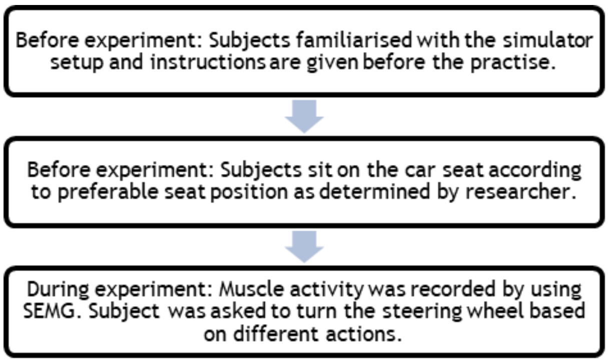


Figure 2- Experiment flow

Subjects were later asked to position themselves in the adjustable seat with both hands at the 10:10 position and in a 'distant position'. Here, distant seated position refers to the distance between the subject and the car controls. Nevertheless, they needed to ensure they could operate the car controls and sat comfortably leaning against the car seat backrest. The backrest position was fixed at 100^{0}. This fixed position was based on a previous study conducted by Daruis[17] and Mohamad et al.[18]. Figure 3 illustrates the required driving position in this study.

Figure 3- Driving posture

Moreover, test subjects were instructed to turn the steering wheel according to certain actions, as demonstrated in Figure 4. The aim of this experiment was to estimate and measure DA muscle activation when operating the steering wheel with respect to the direction of turning (to the right or left) and degree of turning (10 and 45 degree).

Muscle activity measurement

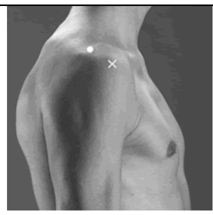
Surface electromyography (SEMG) is a well-known tool to study the function of muscle when controlling the steering wheel. Changes in muscle activity around the shoulder can be observed using SEMG. A Trigno™ Personal Monitor with Parallel-Bar Sensors from Delsys Incorporation was used to collect muscle activity analog data with sample rate of up to 1000Hz interface with 5-channel signal amplifier. The myo-electrical signal of surface was converted to analog data and later converted to digital data on the signal analysis personal computer interface. SEMG measurement was performed by placing electrodes on the subject's skin surface and electrical activity of the left deltoid anterior (DA) was recorded. The procedure of collecting data on selected muscle was in accordance with the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) recommendations.

Figure 4- Main actions in steering wheel

Data collection preparation based on SENIAM recommendation

Skin inspection was performed prior to placing the electrodes. The main purpose was to reduce skin impedance and avoid noises on the EMG readings. Proper skin preparation proved useful in improving electrode-skin contact. All the subjects were shaved at the selected muscle belly, before being cleaned with alcohol, rubbed with gel and abraded with abrasive cream; NuPrep[19]. The EMG electrodes were fixed directly on selected muscles belly after careful palpation, parallel to its muscle fibers. The procedure for electrodes placement such as; body posture, location of electrodes, orientation, clinical test and task for selected muscle are shown in Table 1. Once the electrodes had been placed and fixed, they could then be connected to the SEMG equipment and a clinical test could be performed. This is to determine whether the electrodes have been properly placed on the muscle and connected to the equipment in order for a reliable SEMG signal to be recorded.

Table 1- Identification of selected muscle and electrode placement position

Muscle	Starting posture	Electrode placement	Clinical test	Orientation
DA	Sitting with the arms hanging vertically and the palm pointing inwards	The electrodes need to be placed at one finger width distal and anterior to the acromion.	Shoulder abduction in slight flexion, with the humerus in slight rotation. In the erect sitting position it is necessary to place the humerus in slight lateral rotation to increase the effect of gravity on the anterior fibres. The anatomical action of the anterior deltoideus entails slight medial rotation while pressure is applied against the antero medial surface of the arm in the direction of adduction and slight extension.	

Source: SENIAM[20]

Muscle activity analysis

Figure 5 shows the flow chart of SEMG data analysis. Matlab and Microsoft Excel were used for analysing SEMG data in this study. As shown in Figure 5, before analysing SEMG signal data, all data must be filtered using three types of frequencies. This was due to the raw data having unnecessary noise and artefact from the electrode movement. All raw EMG signals were filtered via the band pass and notch filter process. Most of the power in the EMG signal was in the frequency range of 5 to 500 Hz[21-22]. This filter setup was based on SENIAM recommendations and previous studies. There were two types of band pass filter, namely high-pass and low-pass Butterworth filter. It was used to reduce the source of EMG signal noise. In this study, the high-pass and low-pass Butterworth filters of the fourth order were used at cut-off frequencies at 10 Hz and 500 Hz respectively, while the notch filter was set at 50 Hz. Ten Hz was set as cut off frequencies at the high-pass to ensure the signal was adjusted to zeroing line first. Consequently, it could reduce unwanted noise and artefact. Meanwhile, 500 Hz was the next setup for cut-off frequency at the low-pass. Such a frequency was used to reduce biological artefact such as from the body fat which would not be recognized by EMG signal. Therefore, according to SENIAM recommendation, this setup could reduce noise due to this type of artefact. Next, 50 Hz was the setup for the notch filter. This frequency was used to reduce noise signal from any electrical devices such as computer or hand phone found near the experiment location. After the filtering process, the filtered EMG signals were transferred to full-wave rectified signal for Temporal Analysis. Temporal Analysis was conducted to investigate the pattern of muscle when controlling and interacting with certain tasks in driving. After full wave processing, the signals were smoothened at RMS 500 ms. All these processes utilised Matlab processor.

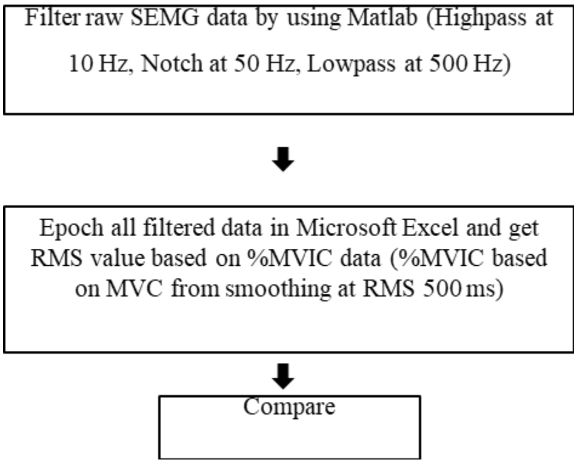


Figure 5- Flow chart of SEMG data analysis

Next, all the signals were epoched in every segment. Epoch refers to segmentation in stipulated time used for analysis. With regard to this study, epoch was obtained at one second for one segment for each activity. After the epoch process, percentage of Maximum Voluntary Isometric Contraction (% MVIC) analysis was required to compare the driving tasks between each subject and each muscle. The purpose of conducting MVIC was to generate maximum muscle voluntarily during isometric muscle contraction. In the MVIC research design, respondents had to perform pre-determined activities, as shown in Table 1 under clinical test. The MVIC reference value was divided by SEMG value which would provide the normalized MVIC percentage value. Microsoft Excel was used for this process. The Amplitude Analysis was gathered based on this value. Amplitude Analysis was carried out to determine muscle activity according to driving condition, either in contraction form or rest form. The value of muscle activity was in Root Mean Square (RMS). If the RMS of muscle activity was lower than 5 microvolt (μV), it meant the muscle was in the rest form[19]. Basically, the Amplitude Analysis was performed at time domain and the amplitude unit was in μV. Amplitude analysis was conducted at the stipulated epoch. The RMS equation in discrete time is defined in the following equation, where N is the number of data and n is the EMG data.

$$R.M.S = \sqrt{\frac{1}{N}\sum_{n=1}^{n} EMG\,[n]^2}$$

RESULTS AND ANALYSIS

Temporal analysis for steering wheel task

As stated in the previous section, Temporal Analysis was conducted to understand muscle pattern when engaged in certain driving tasks. Figures 6 and 7 show the Temporal Analysis for DL and DR response toward steering wheel action after the filtering process. Each action was recorded for approximately five seconds. Based on both figures, it was obvious that the DL and the DR muscle operated oppositely when performing the left and right turn. In general, when turning to the left, the DR muscle showed the highest activation, while when turning to the right, the DL muscle demonstrated the highest activation. Such a pattern was obvious and can be seen in Figures 6 and 7. For instance, when turning the steering wheel to the left, L10 or L45 for the DR muscle was higher than the DL muscle. In contrast, when turning to the right, R10 or R45 for the DR muscle was lower than the DL muscle.

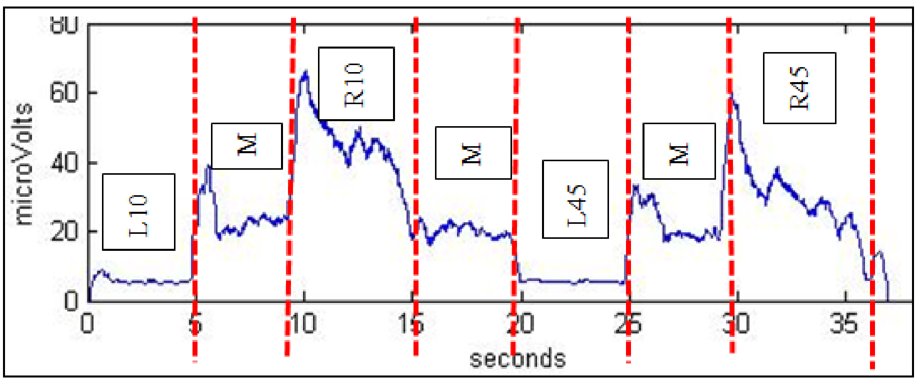


Figure 6- Temporal analysis of DL muscle according to steering wheel task

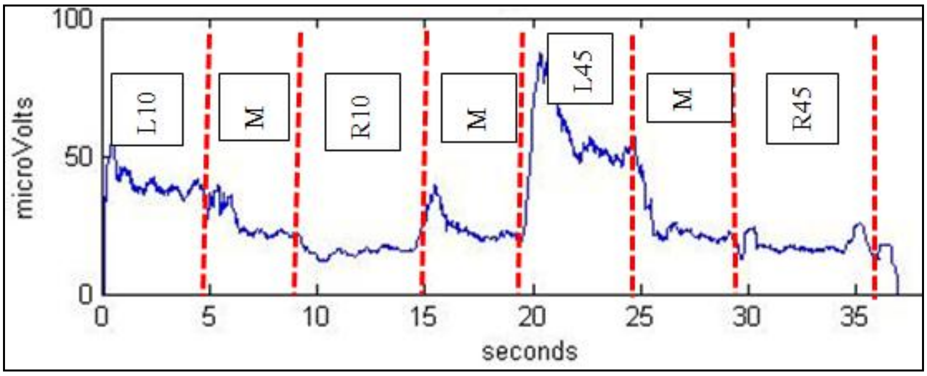


Figure 7- Temporal analysis of DR muscle according to steering wheel task

With respect to the degree of turning, when turning to the left, L10 showed small activation than L45. This was also the situation when turning to the right, whereby L10 depicts the lowest activation than L45. For further analysis in the next subsection, only L10, L45 and R45 were evaluated in details. The aim of this comparison is to investigate pattern of the muscle according to degree of turning and direction of turning. In this case, L10 and L45 (either 10 degree or 45 degree) were compared in terms of the degree of turning, whereas L45 and R45 were compared to identify the working muscle (DL and DR) based on direction of turning (either to the left or right).

Amplitude analysis for steering wheel task

Amplitude Analysis was carried out to determine muscle contraction when engaged in certain driving tasks. Figures 8 and 9 show the Amplitude Analysis in the form of mean RMS values of each steering wheel action for each muscle. As stated in the previous section, each condition had specific value of %MVIC taken for this study. This %MVIC value was presented in the bracket for each action. In Figure 8, for L10 turning of the DL, the mean RMS value was 10.56 μV (6%). For L45 turning, the RMS value was 13.18 μV (8%). For R45 turning, the RMS value was 33.21 μV (23%). Overall, R45 turning had the highest mean RMS.

In Figure 9, a similar increment pattern can be seen for DR muscle, but based on different turning. In terms of turning direction, L45 showed the highest mean with 34.01 (23%). Whereas, R45 indicated the lowest mean RMS with 20.22 μV (13%). Meanwhile, L10 turning showed about 27.64 μV (19%).

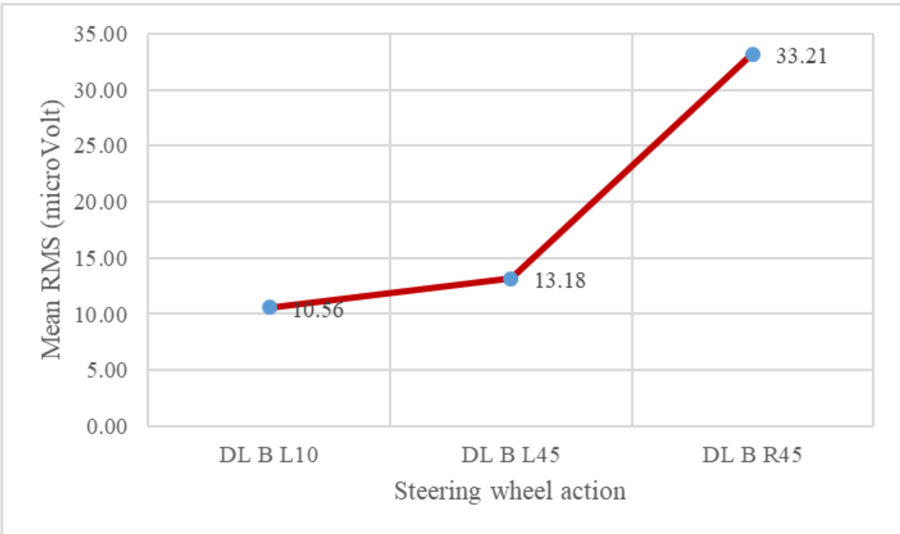


Figure 8- Amplitude analysis of DL for L10, L45 and R45 actions at distant position

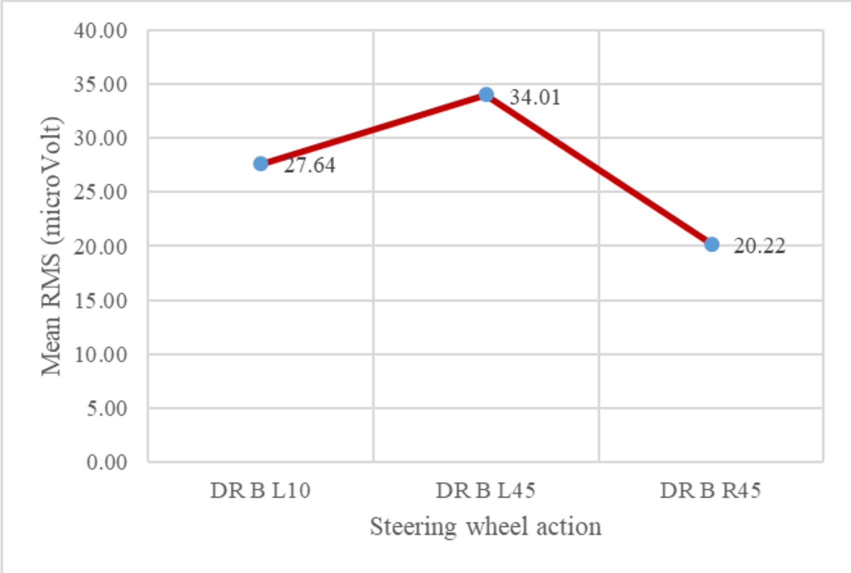


Figure 9- Amplitude analysis of DR for L10, L45 and R45 actions at distant position

Thorough analysis for steering wheel task

A detailed analysis was performed to determine any association between each variable by using statistical analysis. Before the detailed statistical analysis, normal distribution test was performed to determine whether the data was under parametric or non-parametric test. In this section, the difference between the turning degree (10 degree and 45 degree) is investigated using suitable statistical method.

Differences between actions (L10, L45 AND R45) at DL

The objective of this part is to understand whether there was any difference in muscle activity under three actions, L10, L45 and R45. There was a statistically significant difference in muscle activity under three actions, x2(2) = 13.556, p = 0.001. Median muscle activity for the L10, L45 and R45 were 3.48 (2.47 to 7.12), 3.73 (2.66 to 4.12) and 39.02 (18.91 to 48.40) respectively. There was a statistically significant difference between L10-R45 (Z=-2.666, p=0.008) and L45-R45 (Z = -2.666, p = 0.008).

Differences between actions (L10, L45 AND R45) at DR

There was a statistically significant difference in muscle activity under three actions, x2(2) = 10.889, p = 0.004. Median muscle activity for the L10, L45 and R45 were 16.27 (6.27 to 28.05), 17.12 (9.88 to 40.54) and 5.27 (3.35 to 20.11) respectively. The result shows that L10-L45 as well as L45-R45 had significant differences, (Z=-2.666, p=0.008) and (Z=-2.547, p=0.011).

DISCUSSION

The deltoid was also worked to stabilize scapular movement to achieve scapulohumeral rhythm. Scapular motions are synchronized with motions of humerus. When turning the steering wheel to left, the right shoulder move in midrange of flexion and abduction whereby such an action requires the scapula to have greater motion approaching 1:1 ratio with glenohumeral joint. The synchronous motion of the scapula allows muscles moving humerus to maintain an effective length-tension relationship throughout the activity. This helps to maintain congruency between humeral head and glenoid fossa while decreasing in shear forces. The dynamic control will lead to the ability in functional elevation of arm for turning the steering wheel to the left. In addition, with more degrees of turning, more muscle activation will be produced, that can be explained through Temporal Analysis and Amplitude Analysis.

CONCLUSION

Hand placement while coordinating the steering wheel is expected to trigger shoulder muscle activity. The finding of this study is supported by the principle of muscle loading to shoulder joint movement while driving and coordinating the steering wheel. In this study, DL and DR worked oppositely depending on turning. For instance, DL was highly activated when rotating steering wheel to the right in short duration of driving. The action required shoulder joint to perform with an increased range of left shoulder flexion. The DL worked concentrically to provide more range of shoulder into flexion.

Comparatively, the study found significant difference between the DR and the DL in terms of muscle activation signal pattern when turning the steering wheel to the left, to the middle and to the right. The deltoid is the prime mover for shoulder flexors and shoulder abduction, which work concentrically. The findings from this study correlated with the function of the muscle to move and control the shoulder in driving. When the hand grip turned the steering wheel to the left, the right shoulder experienced high activation to increase range in shoulder flexion and abduction. In contrast, when the steering wheel was turned to the right, the right deltoid was inhibited to allow the right shoulder to adduct. Therefore, the study proves that the placement of hand while coordinating steering wheel will affect the activation of shoulder muscle, especially the deltoid. In general, the deltoid is the most active muscle in maintaining the arm in a raised position.

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COMPETING INTERESTS

There is no conflict of interest.

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